Universidade de Lisboa

Faculdade de Medicina Dentária

Comparative analysis of simulated root canals shaping using TRUShape®, ProTaper Gold™ and HyFlex® EDM

Cristina Sterbet

Dissertação

Mestrado Integrado em Medicina Dentária

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Dissertação orientada
Pelo Prof. Doutor António Ginjeira

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RESUMO

INTRODUÇÃO: Endodontia é o termo grego resultante da junção entre "endotologia" (dentro) e "odontos" (dente). De acordo com a Sociedade Europeia de Endodontia, este ramo da Medicina Dentária é uma área dedicada ao estudo da forma, função e saúde de lesões e doenças da polpa dentária e região peri radicular, a sua prevenção e tratamento.

Os objetivos básicos do tratamento endodôntico prendem-se com a eliminação dos microrganismos e tecido pulpar infetado assim como com a criação de um ambiente que permita a cicatrização dos tecidos peri apicais prevenindo assim o desenvolvimento de periodontite apical.

Aquando da instrumentação, deve-se manter a configuração original do canal radicular sem a criação de quaisquer atos iatrogénicos tal como o transporte apical. No final deste processo, o canal radicular deve apresentar uma forma cónica com a constrição apical mantida permitindo assim um correto selamento hermético do sistema canalar. A existência de curvaturas acentuadas nos canais radiculares é um fator que dificulta a obtenção dos objetivos acima referidos e tem-se tornado um desafio ao longo destes anos.

A evolução dos instrumentos utilizados na área da Endodontia tem sido constante ao longo do tempo. A forma mais antiga e tradicional de instrumentação do canal radicular é feita com limas manuais de aço inoxidável, tendo estas a desvantagem de apresentarem uma flexibilidade reduzida, o que cria uma certa limitação na instrumentação de canais curvos, tendendo a fraturar e podendo ocorrer transporte do canal. Deste modo, ocorreu a necessidade de se criarem novos instrumentos capazes de ultrapassarem esses obstáculos.

A introdução de instrumentos rotatórios de NiTi, melhorou de uma forma geral a qualidade da instrumentação dos canais radiculares assim como a redução de erros aquando da mesma. No entanto, apesar das suas inúmeras vantagens, os instrumentos rotatórios NiTi apresentam risco de fratura ao instrumentar canais curvos devido à aplicação repetida de forças de torção, levando à fadiga cíclica.

Uma nova era no desenvolvimento de instrumentos rotatórios NiTi começou com a criação da liga NiTi M-Wire há cerca de 10 anos. Esta nova liga mostrou resistência à fadiga cíclica significativamente superior nos instrumentos rotatórios endodônticos em comparação com instrumentos feitos de ligas de NiTi super elásticas convencionais.

OBJECTIVOS: O objetivo deste estudo foi comparar a eficiência na manutenção da anatomia do canal radicular analisando a quantidade de material removido nos blocos de resina acrílica com curvatura em forma de S, utilizando 3 diferentes sistemas rotatórios: ProTaper Gold™ (PTG), TRUShape® (TS) and HyFlex® EDM (HF).

MATERIAIS E MÉTODOS: Foi utilizada uma amostra total de 36 blocos de resina acrílica com canais curvos em forma de S distribuídos aleatoriamente por 3 grupos de 12 canais cada. Cada grupo de 12 foi instrumentado por um sistema rotatório diferente: Grupo A - ProTaper Gold™; Grupo B - TRUShape® e Grupo C - HyFlex® EDM. Cada canal foi instrumentado até um calibre de 0.25 mm e um comprimento de trabalho de 16 mm.

Para se efetuar a análise quantitativa, foram tiradas fotos antes e após a instrumentação dos 36 blocos de resina utilizando uma câmara digital e com a ajuda de uma plataforma específica para que as fotos fossem todas tiradas na mesma posição e à mesma distância. Foi determinado o eixo médio do canal e identificados os pontos de medição correspondentes às curvaturas coronais e apical, através da interceção de duas retas tangentes de cada curva utilizado o Rhinoceros Software. As imagens pré-instrumentação e pós-instrumentação dos canais foram sobrepostas utilizando o programa Adobe Photoshop através da redução da opacidade da imagem pós-instrumentada. A largura do canal provocada pela instrumentação foi medida através da distância da margem exterior do canal pré-instrumentado e pós-instrumentado com recurso a uma aplicação de dimensões existente no Rhinoceros Software. Estes valores foram obtidos à escala real.

Foi também efetuada uma análise qualitativa da manutenção ou não, da anatomia original do canal. Foram escolhidos seis examinadores (dois especialistas em endodontia, dois médicos dentistas inexperientes e dois alunos do curso de medicina dentária) para fazer a avaliação de 9 imagens escolhidas de forma aleatória, 3 imagens para cada grupo de sistema rotatório.

Foi feita a análise estatística com recurso ao programa IBM SPSS® versão 25.0, recorrendo aos testes Shapiro-Wilk e Kruskal Wallis. As comparações múltiplas foram automaticamente ajustadas com a correção de Bonferroni. Foram considerados valores estatisticamente significativos com $p < 0.05$.

RESULTADOS: Os resultados revelaram que não houve diferenças significativas no transporte total do canal. Não houve diferenças estatisticamente significativas entre os três grupos quanto ao transporte coronal ou transporte apical.

No lado externo, apenas os grupos A e C apresentaram diferenças estatisticamente significativas ($p<0,05$). No lado externo foi observado mais transporte canalar no grupo A quando comparado com o grupo C. O grupo A também apresentou mais transporte canalar do lado externo e na curvatura apical do que o grupo C.

DISCUSSÃO: O objetivo deste estudo foi comparar a capacidade de instrumentação de diferentes sistemas NiTi: ProTaper Gold ™; TRUShape®; HyFlex® EDM usando canais simulados em forma de S para padronizar as condições experimentais, mas sempre considerando o facto de que este método fornece apenas dimensões 2D. A PTG, em vários estudos, apresentou bons resultados quando comparada com outros sistemas rotativos. HF e TS são dois sistemas rotativos inovadores que foram recentemente introduzidos no mercado. Estudos pré e pós-instrumentação indicam que a análise dos contornos do canal radicular fornece um desenho de estudo padronizado e condições extremamente reprodutíveis. Os sistemas endodônticos rotativos eram do mesmo tamanho mas com diferentes movimentos, conicidades, número de espiras, processos de fabricação, velocidades e torques na área de corte. A primeira etapa do estudo compreendeu uma análise quantitativa através da observação de alterações na anatomia do canal radicular entre imagens pré e pós-instrumentação, seguida de uma observação qualitativa feita pelos examinadores para comparar a manutenção da anatomia do canal radicular original. É importante referir que não existe nenhum estudo na literatura que compare PTG, TS e HF, portanto não é possível comparar diretamente os resultados deste estudo com outros. Com base nos resultados obtidos na análise quantitativa, a hipótese nula foi rejeitada. Os resultados revelaram que não houve diferença estatisticamente significativa no transporte total do canal. Não houveram diferenças estatisticamente significativas entre os três grupos quanto ao transporte coronal ou transporte apical. No lado externo, apenas os grupos A e C apresentaram diferenças estatisticamente significativas. Foi observado mais transporte canalar no grupo A - PTG quando comparado com o grupo C - HF. O PTG também apresentou mais transporte canalar do que HF no lado externo e na curvatura apical. Na literatura, mas não diretamente relacionados, existem alguns estudos que suportam os resultados obtidos. Os instrumentos de HF apresentaram maior resistência à fadiga cíclica quando comparados com o PTG. (Kaval *et al*, 2016).

Um estudo recente que comparou TR e PTG revelou que os instrumentos TR apresentaram menor resistência à fadiga cíclica e menor flexibilidade em comparação com o PTG (Elnaghy e Elsaka, 2017), o que não condiz com os resultados obtidos neste estudo.

A segunda etapa do estudo compreendeu uma análise qualitativa em que endodontistas, clínicos inexperientes e estudantes avaliaram a manutenção da anatomia do canal radicular original, com a presença ou ausência da retificação das curvaturas coronais e apicais. As diferenças registadas devem-se à experiência clínica e aos diferentes níveis de conhecimento endodôntico.

Algumas críticas para o presente estudo são a existência de curvaturas de alta amplitude nos dentes naturais, temperatura diferente na cavidade oral e o facto do procedimento de instrumentação ter sido executado com o bloco de resina a ser segurado pela mão do operador.

CONCLUSÃO: Sob as limitações deste estudo, a HyFlex® EDM foi o sistema rotatório que melhor manteve a anatomia original do canal em forma de S com menos modificação nas curvaturas coronal e apical, revelando mais flexibilidade em comparação com a ProTaper Gold ™ e TRUShape®. A ProTaper Gold ™ foi o sistema que originou a maior modificação do canal original, apresentando uma tendência significativa para transporte canalar na curvatura apical e no lado externo. Durante a prática clínica, os médicos-dentistas devem estar cientes das propriedades mecânicas dos instrumentos escolhidos para melhor adaptarem as limas dos sistemas rotatórios a cada caso específico. É importante respeitar a anatomia original do canal e evitar o transporte apical para que o tratamento endodôntico não seja comprometido.

PALAVRAS-CHAVE: ProTaper Gold™; TRUShape®; HyFlex® EDM; instrumentação canalar; endodontia

ABSTRACT

INTRODUCTION: The evolution of endodontic instruments has been constant over the time. At instrumentation, the original configuration of the root canal should be maintained without creating any iatrogenic act. The introduction of NiTi rotary instruments has generally improved the quality of instrumentation.

AIM: The objective of this study was to compare the efficiency of the maintenance of the root canal anatomy by analysing the amount of material removed in the S-shaped curved acrylic resin blocks using different systems: ProTaper Gold ™, TRUShape® and HyFlex® EDM.

MATHERIALS AND METHODS: A quantitative analysis was made by measuring the canal of 36 samples, distributed by three groups of 12 samples each (Group A - ProTaper Gold™; Group B - TRUShape® and Group C - HyFlex® EDM), by superimposed images of pre and post instrumentation using Rhinoceros Software. In the qualitative analysis, blinded examiners evaluated 3 images from each group and refer the presence or absence of rectifications in the coronal and apical curvatures. The statistical analysis was obtained by using the Shapiro-Wilk and Kruskal Wallis test. Multiple comparisons were automatically adjusted with the Bonferroni correction with a significance of $p<0.05$.

RESULTS: There were no statistically significant differences on canal transportation ($p<0.05$). Only groups A and C presented significant statistically differences on the outer side and on the outer side at apical curvature. More canal transportation was observed in group A when compared with group C.

CONCLUSION: It might be assumed that HyFlex® EDM was the rotary system that has more respect for original canal anatomy. Higher flexibility might be the predominant propriety responsible by these results. ProTaper Gold ™ was the system that originated the greatest modification of the original canal, presenting a significant tendency to straightened apical curvature and outer side.

KEYWORDS: ProTaper Gold™; TRUShape®; HyFlex® EDM; root canal shaping; endodontics

SYMBOLS, ABBREVIATIONS AND UNITS

Symbols

% - percentage

p - significance

® - registered trademark

™ - unregistered trademark

$\bar{x}$ - sample mean

s - sample standard deviation

Abbreviations

2D – two dimensional

3D – three dimensional

NiTi – Nickel-Titanium

AP – apical

CM – controled memory

CO – coronal

DSLR – Digital Single-lens Reflex

HF – HyFlex® EDM

IQR – interquartile range

PTG – ProTaper Gold™

PTU – ProTaper Universal™

TS – TRUShape®

Units

mm - millimeters

N cm - Newton centimeter

rpm - rotations per minute

kg/mm2 – kilogram per square millimiter

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1. INTRODUCTION

1.1. Endodontics – definition

The word "endodontology" is derived from the Greek language and can be translated as "the knowledge of what is inside the tooth". According to the European Society of Endodontology (2006), endodontology is an area devoted to the study of the form, function and health of, injuries to and diseases of the dental pulp and periradicular region, their prevention and treatment; the principle disease being apical periodontitis, caused by infection. American Association of Endodontists defines endodontics as a subdivision of dentistry concerned with the morphology, physiology and pathology of the human dental pulp and periradicular tissues; its study and practice encompass the basic and clinical sciences including the biology of the normal pulp and the aetiology, diagnosis, prevention and treatment of diseases and injuries of the pulp and associated periradicular conditions. Although these differences on vocabulary, in general it reflects the same content.

1.2. Endodontics – aim

The overall aim of dentistry and dental practice is to maintain a healthy and natural oral cavity. The aim of endodontic treatment is to preserve functional teeth. Endodontics has as main objective the differential diagnosis and treatment of pain, whether it is of pulp origin, periapical or both. Endodontic treatment is necessary when the pulp, the soft tissue inside the root canal, becomes inflamed or infected. The inflammation or infection can have a variety of causes: deep caries with pulp involvement, dental fractures, dental trauma, injury, prosthetic and other endodontic pathologies.

The basic objectives of endodontic treatment are the elimination of microorganism and infected pulp tissue as well as the creation of an environment that will allow the healing of peri-apical tissues and prevent the development of apical periodontitis. (Fleming *et al*, 2010)

One of the main objectives of root canal preparation is to shape and clean the root canal system effectively whilst maintaining the original configuration without creating any iatrogenic events such as external transportation, ledge or perforation. (Ruddle, 2002)

However, in cases of severely curved canals, traditional stainless-steel instruments often fail to achieve the tapered root canal shapes needed for adequate cleaning and filling. (Al Omari *et al*, 1992)

1.3. Evolution of rotary system

The evolution of instruments used in endodontics area has been constant over the time. The oldest and most traditional form of root canal instrumentation is made with stainless steel windows instruments, having the disadvantage of a reduced flexibility, which creates a certain limitation on the instrumentation of curved channels.

Therefore, in order to try to solve these problems, Nickel-titanium (NiTi) continuous rotary techniques have been introduced in 1992 by Dr. John T. McSpadden. This alloy has unique properties, is resilient, tough, and has a low elastic modulus, improving both the morphological characteristics and safety of canal shaping. (Thompson, 2000)

However, despite their numerous advantages, the NiTi rotary instruments present risk of fracture when rotating in curved canals due to repeated tensile-compressive forces being applied to the file in maximum curved areas, leading to cyclic fatigue. (Ankrum *et al*, 2004; Arias *et al*, 2012)

Recently, a new era has started in the development of NiTi rotary instruments with the creation of M-Wire NiTi alloy. Is made by thermomechanical process which is frequently used to optimize the microstructure and transformation behavior of NiTi alloys, which in turn has greater influence on the mechanical properties of NiTi files. (Hieawy *et al*, 2015)

This new NiTi wire has showed significantly improved cyclic fatigue resistance on endodontic rotary instrument products in comparison with those made of conventional super elastic NiTi alloys. MWire contains all 3 crystalline phases, including deformed and micro twinned martensite, R-phase, and austenite, being a more flexible alloy. (Ye *et al*, 2012; Arias *et al*, 2015; DENTSPLY Tulsa Dental Specialties)

1.4. Rotary instruments

Several studies have been conducted to find a working system that best respects the anatomy of the canals. The purpose of this study was to analyse and compare three different rotary systems: ProTaper Gold™; TRUShape®; HyFlex® EDM with the glide path established by ProGlider®.

1.4.1. ProGlider®

An important step in endodontic procedure is the creation of a glide path, with the goal of securing the root canal path before the use of a shaping file system. A ProGlider® file, is a single file glade path instrument made with M-Wire® NiTi alloy, with a tip size 16/.02 with a variable progressive taper (**Figure 1**).

The manufacturer advocates that it creates a glide path faster, is suitable for most root canals, including the highly curved ones whilst respecting the root canal anatomy when compared to manual files or another alternative rotary glide path solution. (Dentsply Maillefer; Ruddle *et al*, 2014)

Figure 1 - ProGlider® is a single file glade path instrument made with M-Wire® NiTi alloy, with a tip size 16/.02 (Dentsply Maillefer)

1.4.2. ProTaper Gold™

A few years ago, ProTaper Gold™ (PTG) rotary instruments were introduced, maintaining the geometric design and convex triangular cross-sectional shape of the ProTaper Universal™ (PTU) rotary instrument system adding the advantage of the improved properties of gold wire technology as increased flexibility and resistance to fracture. The manufacturer claims that PTG instruments have resistance to cyclic fatigue and maintain canal centring, especially when preparing challenging curves in the apical region. (DENTSPLY Tulsa Dental Specialties; Ruddle *et al*, 2014)

PTG system consist of 3 shaping files (SX, S1, and S2) responsible for shaping the coronal and mesial portion of the canal and designed to be used with outstroke brushing technique. Also have 5 finishing files (F1, F2, F3, F4, and F5), which prepare the apical portion of the canal and only can be used until they reach the full working length, all in different lengths (21, 25 and 31 mm) with a progressive taper (**Figure 2**). (Bayram *et al*, 2017)

Sx, S1, S2, F1 and F2 have a convex triangular cross section while F3, F4 and F5, present a concave triangular cross section. The sequence of this rotary system is SX, S1, S2, F1, F2, F3, F4 and F5.

Shaping File S1 (18/.20) and S2 (20/.04), have purple and white identification rings on their handles, respectively. The Auxiliary Shaping File, termed SX (19/.04), has no identification ring on its gold-coloured handle and, with a shorter overall length of 19 mm, provides excellent access when space is restrictive. Five Finishing files named F1(20/.07), F2 (25/.08), F3(30/.09), F4 (40/.06) and F5 (50/.05) have yellow, red, blue, double black and double yellow identification rings on their handles, respectively. (Ruddle, 2007)

Figure 2 - ProTaper Gold™ systems consist of 3 shaping files (SX, S1, and S2) and 5 finishing files (F1, F2, F3, F4, and F5) (Dentsply Maillefer)

1.4.3. TRUShape®.

Recently, a novel NiTi alloy with proprietary processing rotary system named TRUShape® (TS) 3D Conforming Files was introduced. The files for this system are provided in the following configurations: TS orifice modifiers – tip size 20/.08 and four TS 3D conforming files - tip sizes 20/.06 (yellow), 25/.06 (red), 30/.06 (blue), and 40/.06(black) available in lengths of 21 mm, 25 mm, and 31 mm (**Figure 3**). The files with tip size 30/.06 and 40/.06 are optional. TS Orifice Modifiers has an active cutting cross section, a fluted length of 7 mm witch creates an ideal receptacle for the introduction of the conforming file. (De Siqueira Zuolo *et al*, 2016)

According to the manufacturer, the design of the instruments allows them to contact more to the canal walls and allow for less transportation and removal of the dental structure. (De Siqueira Zuolo *et al*, 2016) The key to the TS difference lies in the file's unique S-shape design (**Figure 4**), allowing it to conform to areas of the canal larger than the nominal file size. TS files are better at disrupting polymicrobial biofilms in mesial roots of lower molars and leave significantly less bacteria when compared to conventional ISO rotary file systems. (DENTSPLY Tulsa Dental Specialties)

Figure 3 - TRUShape® orifice modifiers tip size 20/.08 and conforming files - tip sizes 20/.06 (yellow), 25/.06 (red), 30/.06 (blue), and 40/.06(black) (DENTSPLY Tulsa Dental Specialties)

1.4.4. HyFlex® EDM

Coltene-Whaledent introduced, the new HyFlex® EDM (HF) NiTi rotary files that correspond to a one file system. HF files are produced from the same CM wire, similar to HyFlex CM but using an innovative manufacturing process called Electrical Discharge Machining. (Daneshmand et al, 2013) These files are the first endodontic instruments manufactured with this procedure. (Pirani et al, 2016) This process uses spark erosion to harden the surface of the NiTi file which manufacturer claims to result in a file that is extremely flexible allied to a high fracture resistant. (Coltene, 2017)

The combination of flexibility, fracture resistance and cutting efficiency of the HF make it possible to reduce the number of files required for cleaning while preserving anatomy. These files have controlled memory properties which gives the ability to return to a pre-set shape when heated.

HF includes: orifice opener (25/.12) that creates access opening and its optional, a glidepath file (10/.05), an HyFlex OneFile (25/~) that is a unique file for shaping and has a variable taper and finishing files (40/.04; 50/.03 and 60/.02) that are optional (**Figure 4**).

The built-in shape memory of HF files prevents stress during canal preparation by changing their spiral shape. Regeneration and recovery of the spiral shape is made by thermal treatment. A normal autoclaving process is enough to return the files to their original shape and fatigue resistance (**Figure 5**). (Coltene, 2017)

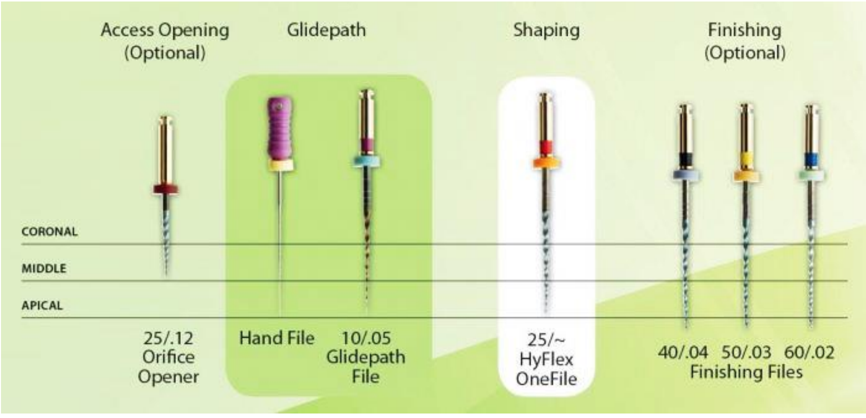


Figure 4 - HyFlex® EDM files: orifice opener (25/12); glidepath file (10/05); HyFlex OneFile (25/~) and finishing files (40/.04; 50/.03 and 60/.02) that are optional (Coltene-Whaledent)

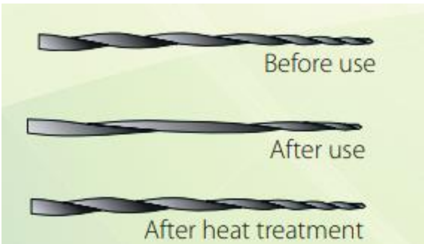


Figure 5 - HyFlex® EDM regeneration and recovery of the spiral shape by thermal treatment (Coltene-Whaledent)

2. AIMS

The purpose of this study is to compare the shaping ability with focus on the maintenance of original anatomy in simulated S-shaped root canals, of three different system files: ProTaper Gold™; TRUShape®; HyFlex® EDM, with the glide path established by ProGlider®.

The S-shaped form has a double curve canal corresponding to the coronal and the apical curvature. Is important to analyse whether the shaping effect is bigger in the inner or outer portion of the curvature and whether the shaping effect is more significant in the coronal or apical curvature.

Specific goals:

More specifically, the following hypothesis was tested regarding overall transportation irrespective of location, and also considering curvature, side and then both simultaneously:

H0 - Transportation is alike in all instruments.

H1 - Transportation is different between instruments

3. MATERIALS AND METHODS

3.1. Simulated Root canals

A total of 36 simulated canal with an S-shaped curvature in clear resin blocks (ISO 15, Endo-Training-Bloc-S .02 Taper; Dentsply-Maillefer, Ballaigues, Switzerlan) were prepared by three different Ni-Ti rotary files system, using the technique recommended by the manufacturer: ProTaper Gold™ (PTG); TRUShape® (TS); HyFlex® EDM (HF).

The resin blocks were randomly numbered from 1 to 12 and then randomly assigned to three different groups, each one prepared by one of the three rotary system files studied **(Figure 6).** Group A corresponds to 12 simulated canal resin blocks, prepared with PTG **(Figure 7)** (Dentsply Maillefer); Group B corresponds to 12 simulated canal resin blocks, prepared with TS (**Figure 8)** (Dentsply Tulsa Dental Specialties) and Group C corresponds to 12 simulated canal resin blocks, prepared with HF (**Figure 9**) (Coltene-Whaledent).

Figure 6 - Simulated canal with an S-shaped curvature in clear resin blocks before instrumentation from de group C (ISO 15, Endo-Training-Bloc-S .02 Taper; Dentsply-Maillefer, Ballaigues, Switzerlan)

Figure 7 - Sterilized ProTaper Gold™ Kit, Sx-F3, 25mm (Dentsply Maillefer)

Figure 8 - Sterilized TRUShape® Kit (Dentsply Tulsa Dental Specialties)

Figure 9 - Sterilized HyFlex® EDM Kit (Coltene-Whaledent)

A specific platform allowed to take pictures of the canals before and after instrumentation using a precise camera (Olympus Digital Camera E500) and a repositioning of the resin blocks (**Figure 10**).

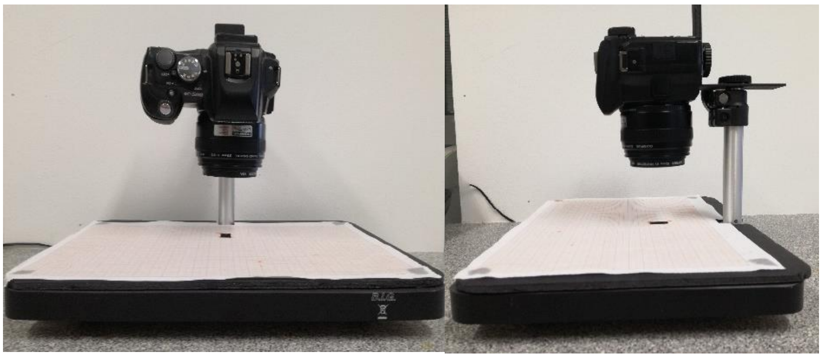


Figure 10 - Reproduction table (Kaiser Fototechnik GmbH & Co.KG) and digital camera (Olympus Digital Camera E500)

3.2. Canal instrumentation

The working length in each simulated canal prepared of all the groups was 16 milimeters stablished by advancing a 10K stainless-steal hand file (Dentsply-Maillefer, Ballaigues, Switzerland). The final apical preparation in Group A was set to F2, in Group B set to TS 3D conforming file 25/.06 and in Group C was set to HyFlex OneFile (25/~). The motor settings used- speed and torque – were as recommended by each manufacture of the different system rotary files, using a reduction hand-piece powered by an electric motor (Tecnika, Dentsply Maillefer, Schools Grant Program) (**Figure 11**).

Figure 11 – Electric motor (Tecnika, Dentsply Maillefer, Schools Grant Program)

The instruments were used with slow in-and-out pecking movements, the blades were cleaned after three/four in and out movements using gauze soaked with water and copious irrigation with water was performed throughout the entire preparation sequence after the use of each file for all samples, using a disposable syringe (Injekt®) and 27-gauge irrigation needle (BD Microlance™). A 10 K-file was used to remove debris. Each set of instruments was discarded after use in 6 resin blocks except for the HF files which were used in 12 resin blocks. All canals were prepared by the same operator. The operator had no experience using these rotary files.

3.2.1. Sequence

The following preparation sequences were made, after all canals were scouted up to the working length with a #10 stainless-steal K-file and a ProGlider® file (Dentsply-Maillefer) (**Figure 12**). ProGlider® file was used with an endodontic motor, at a speed of 300 rpm with light apical pressure and set at 2 N cm for torque control.

Figure 12 - Sterilized ProGlider Kit, six files, 25mm (Dentsply Maillefer)

Group A

ProTaper Gold™ files were set into rotation. The motor was used at a speed of 300 rpm and a torque-control level of 4 N cm. Instrumentation followed the sequence below, using shaping files up to the working length with brushing movements and using finishing files with in-and-out movements until reach the working length.

1º - S1 instrument (2% taper, size 18) with a brushing action, until working length is reached
2º - S2 instrument (4% taper, size 20) with a brushing action, until working length is reached
3º - F1 instrument (7% taper, size 20) with in-and-out movements, with each insertion deeper than the previous insertion until reach the working length
4º - F2 instrument (8% taper, size 25) with in-and-out movements, with each insertion deeper than the previous insertion until reach the working length

Group B

TRUShape® files were placed inside of the canal with a gentle pecking motion. The motor was used at a speed of 300 rpm and a torque-control level of 3 N cm. Instrumentation followed the sequence below, using files up to the working length with brushing and in-and-out movements until reach the working length.

1º - TRUShape™ Orifice Modifier instrument (8% taper, size 20) to modify the orifice to create a coronal receptacle
2º - TRUShape 3D Conforming File (6% taper, size 20) smooth 2-3 mm amplitude in-and-out motions towards the apex
3º - TRUShape 3D Conforming File (6% taper, 25 size) towards working length in a gentle passive motion

Group C

HyFlex® EDM files were set into rotation after the files were placed in the canal. All HF files were used at 400 rpm and at a torque of up to 2.5 N cm except the Glidepath files, which was used with 300 rpm and at a torque of up to 1.8 N cm. Instrumentation followed the sequence until reach the working length. When the file could not proceed any further, it was moved back 1 mm until the file was free of the walls.

1º - Glidepath (5% taper, size 10) till the working length

2º - HyFlex EDM one file (variable taper, size 25) till the working length is reached

3.3. Image analysis

Pictures pre and post instrumentation of the canals were recorded using a DSLR (Digital Single-lens Reflex) camera (Olympus Digital Camera E500) with a macro lens. To aid to take the photos of the resin blocks with precision and at same position, a specific platform was used (**Figure 10**). The footage was standardized: a landmark was made in each sample as a reference and the resin blocks were all shot at the same distance and placed in the same position using a graph paper.

The Rhinoceros Software (version 6.0; Robert McNell & Associates, Seattle, WA) was used to identify the mean axis of the canal from the pre-instrumentation images and to identify the measure points, corresponding to the coronal and apical curvatures. These measure points resulted from the interception of two tangent lines of each curve, drew by specific curve applications from the program as the sequence is shown below on **Figure 13**.

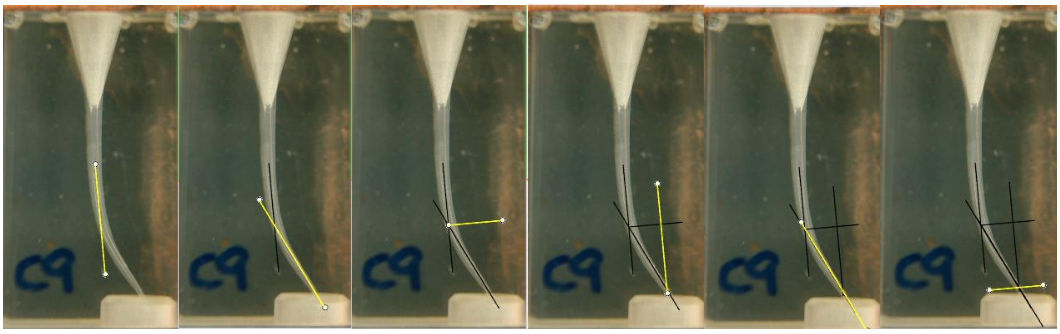


Figure 13 - These six pictures show the sequence made in the Rhinoceros Software to define the measure point of the coronal and apical curvature of the S-shape canal. Two tangents of each curve were trace and intercepted: first coronal curvature tangent; second coronal curvature tangent; interception of the two coronal curve tangent – measure point; first apical curvature tangent; second apical curvature tangent; interception of the two apical curve tangent – measure point.

The overlapping of post instrumentation images over pre-instrumentation images accomplished by reducing the opacity of the post-instrumentation images were made by using a digital imaging software (Adobe Photoshop, version CC 19.1.5 2018; Adobe Systems Inc, San Jose, Ca) (**Figure 14**).

Figure 14 - Post instrumentation digital image superimposed over the pre-instrumentation image (Adobe Photoshop, version CC 19.1.5 2018; Adobe Systems Inc, San Jose, Ca)

With the Rhinoceros Software, there were made measurements to the distance from the centre of the canal to the inner and outer margins of the prepared curve canal in coronal portion and apical portion and in left and right side with a specific measuring application of the program. The distance between the margin of the pre and post instrumentation canal were also registered. Rhinoceros Software allowed to get real measures. These paired images and the measures obtained give a quantitative evaluation of the incidence of canal transportation after mechanical preparation.

To compare maintenance of the original root canal anatomy, a qualitative analysis was done, asking to six blinded examiners with different levels of clinical practice (two endodontic specialists, two inexpert clinicians and two graduation students) if the original coronal and apical curvature were maintained, if less significant straightening occurred or if significant straightening occurred in these curvatures. The examiners evaluated nine superimposed images, randomly chosen, three images from each group.

3.4. Statistical analysis

The statistical analysis was obtained using the IBM SPSS® Statistics version 25.0 software. Descriptive analysis included mean, standard deviation, median and interquartile range values of transportation was described by instrumentation group (A, B and C), curvature (coronal and apical) and side (inner and outter).

Normal distribution was tested with the Shapiro-Wilk test. Since comparisons were made between more than 2 groups and because there was a rejection of the normality test, Kruskal Wallis non-parametric test was used to analyse the results and to compare transportation between groups. Multiple comparisons were automatically adjusted by the software with the Bonferroni correction. Differences were considered statistically significant when $p<0,05$.

4. RESULTS

4.1. Quantitative results

The total amount of material removed was established by measurement of the distance, in mm, between the margin of pre and post instrumentation of the prepared canals, in inner and outer side of both curvatures for the three groups: A (**Table 1**), B (**Table 2**) and C (**Table 3**).

GROUP A	CORONAL CURVATURE		APICAL CURVATURE	
	INNER (mm)	**OUTER (mm)**	**INNER (mm)**	**OUTER (mm)**
A1	0,01	0,27	0,01	0,27
A2	0,1	0,24	0,06	0,26
A3	0,13	0,3	0,05	0,3
A4	0,01	0,33	0,13	0,2
A5	0,08	0,26	0,11	0,31
A6	0,06	0,32	0,05	0,37
A7	0,01	0,31	0,14	0,2
A8	0,2	0,26	0,13	0,33
A9	0,2	0,25	0,12	0,2
A10	0,13	0,32	0,1	0,2
A11	0,11	0,29	0,14	0,3
A12	0,2	0,26	0,12	0,21
Total	**1,24**	**3,41**	**1,16**	**3,15**

Table 1 - Group A – ProTaper Gold™. Measures obtained with the Rhinoceros Software. The distance, in mm, between the margin of pre and post instrumentation of the prepared canals, in inner and outer side, coronal and apical curvatures

GROUP B	CORONAL CURVATURE		APICAL CURVATURE	
	INNER (mm)	**OUTER (mm)**	**INNER (mm)**	**OUTER (mm)**
B1	0,15	0,18	0,09	0,35
B2	0,09	0,22	0,07	0,22
B3	0,1	0,16	0,06	0,17
B4	0,07	0,24	0,1	0,14
B5	0,09	0,37	0,08	0,1
B6	0,1	0,22	0,08	0,12
B7	0,1	0,44	0,05	0,2
B8	0,18	0,26	0,04	0,34
B9	0,19	0,19	0,05	0,23
B10	0,01	0,4	0,07	0,23
B11	0,01	0,41	0,12	0,13
B12	0,15	0,28	0,13	0,15
Total	**1,24**	**3,37**	**0,94**	**2,38**

Table 2 - Group B – TRUShape®. Measures obtained with the Rhinoceros Software. The distance, in mm, between the margin of pre and post instrumentation of the prepared canals, in inner and outer side, coronal and apical curvatures

GROUP c	CORONAL CURVATURE		APICAL CURVATURE	
	INNER (mm)	**OUTER (mm)**	**INNER (mm)**	**OUTER (mm)**
c1	0,09	0,3	0,01	0,17
c2	0,13	0,28	0,06	0,09
c3	0,11	0,21	0,12	0,21
c4	0,01	0,39	0,15	0,16
c5	0,13	0,23	0,13	0,26
c6	0,1	0,28	0,05	0,14
c7	0,18	0,19	0,1	0,1
c8	0,1	0,25	0,14	0,16
c9	0,21	0,22	0,14	0,15
c10	0,17	0,17	0,11	0,17
c11	0,17	0,18	0,11	0,11
c12	0,09	0,29	0,01	0,16
Total	**1,49**	**2,99**	**1,13**	**1,88**

Table 3 - Group C – HyFlex® EDM. Measures obtained with the Rhinoceros Software. The distance, in mm, between the margin of pre and post instrumentation of the prepared canals, in inner and outer side, coronal and apical curvatures

On total canal transportation, there were no statistically significant differences between the three groups, regarding total amount of material removed (p=0.239, **Table 4**)

Instrumentation system	TRANSPORTATION		
	$\bar{x}$ (s)	**Median**	**p**
A – PTG	0,19	0,20 (0,16)	0,239
B – TS	0,17	0,15 (0,13)	
C - HF	0,16	0,15 (0,09)	

Table 4 – Descriptive statistics for transportation by instrumentation system. $\bar{x}$: sample mean; *s:* sample standard deviation; IQR: interquartile range

Analysing coronal and apical curvature separately, there were no statistically significant differences between the three groups regarding coronal transportation (p=0,801) or apical transportation (p=0,169, **Table 5**).

Curvature	TRANPORTATION (mm)						P
	A - PG		**B – TS**		**C – HF**		
	$\bar{x}$ (*s*)	**Median (IQR)**	**$\bar{x}$ (*s*)**	**Median (IQR)**	**$\bar{x}$ (*s*)**	**Median (IQR)**	
CORONAL	0,19 (0,11)	0,22 (0,18)	0,19 (0,12)	0,18 (0,15)	0,19 (0,09)	0,18 (0,12)	0,801
APICAL	0,18 (0,10)	0,17 (0,15)	0,14 (0,09)	0,12 (0,11)	0,13 (0,06)	0,14 (0,06)	0,169

Table 5 - Descriptive statistics for transportation by instrumentation system and cruvature. $\bar{x}$: sample mean; *s:* sample standard deviation; IQR: interquartile range

Differences between the three groups on the outer side were statistically significant (p = 0.003). After multiple comparisons, only groups A and C presented statistically significant differences (p = 0.002) and more canal transportation was observed in group A – PTG (**Table 6**).

Side	TRANPORTATION (mm)							
	A – PG		B – TS		C – HF		P	Multiple Comparisons
	x̄ (*s*)	**Median (IQR)**	**x̄ (*s*)**	**Median (IQR)**	**x̄ (*s*)**	**Median (IQR)**		
INNER	0,10 (0,04)	0,11 (0,07)	0,08 (0,03)	0,08 (0,04)	0,09 (0,05)	0,11 (0,08)	0,288	
OUTER	0,26 (0,06)	0,27 (0,11)	0,20 (0,08)	0,19 (0,09)	0,16 (0,05)	0,16 (0,04)	**0,003**	**p=0,002** (C vs. A)

Table 6 - Descriptive statistics for transportation by instrumentation system and canal side. x̄: sample mean; *s:* sample standard deviation; IQR: interquartile range

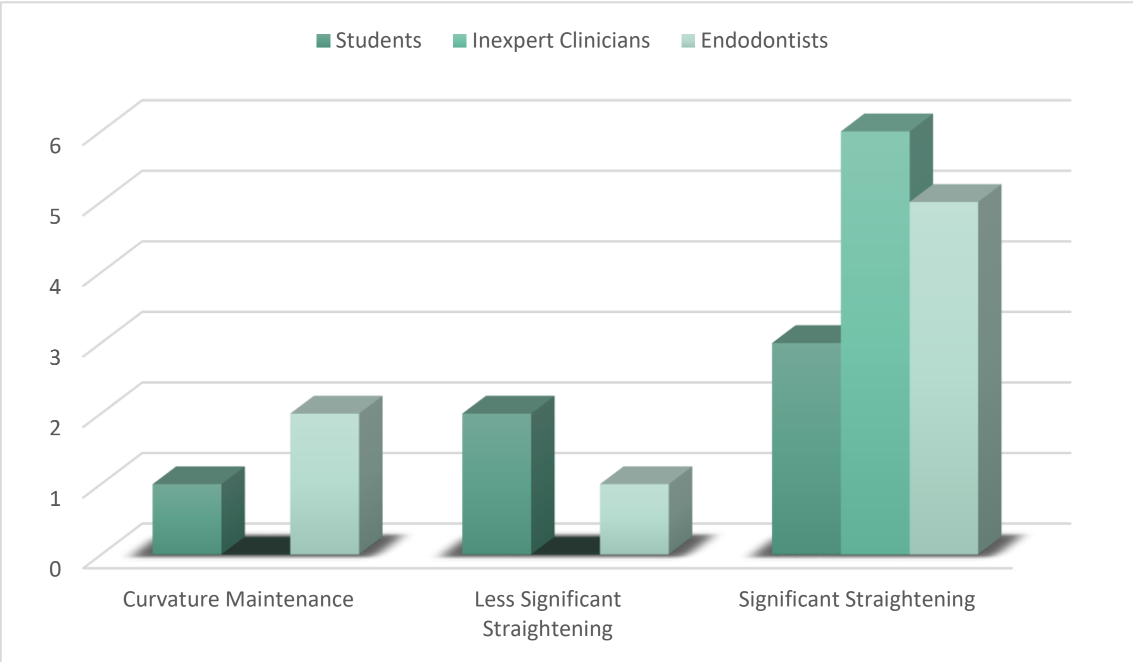
Differences between the three groups on the outer side at apical curvature were statistically significant (p = 0.003). After multiple comparisons, only groups C and A presented statistically significant differences (p = 0.002) and more canal transportation was observed in group A – PTG. (**Table 7**)

Curvature	Side	TRANPORTATION (mm)							
		A – PG		**B – TS**		**C – HF**			
		x̄ (*s*)	Median (IQR)	x̄ (*s*)	Median (IQR)	x̄ (*s*)	Median (IQR)	p	**Multiple Comparisons**
CO	**INNER**	0,10 (0,07)	0,11 (0,14)	0,10 (0,06)	0,10 (0,07)	0,12 (0,05)	0,12 (0,07)	0,619	
	OUTER	0,28 (0,03)	0,28 (0,06)	0,28 (0,10)	0,25 (0,18)	0,25 (0,06)	0,24 (0,09)	0,229	**p=0,002** (C vs. A)
AP	**INNER**	0,10 (0,04)	0,11 (0,07)	0,08 (0,03)	0,08 (0,04)	0,09 (0,05)	0,11 (0,08)	0,333	
	OUTER	0,26 (0,06)	0,27 (0,11)	0,20 (0,08)	0,19 (0,09)	0,16 (0,05)	0,16 (0,04)	**0,003**	

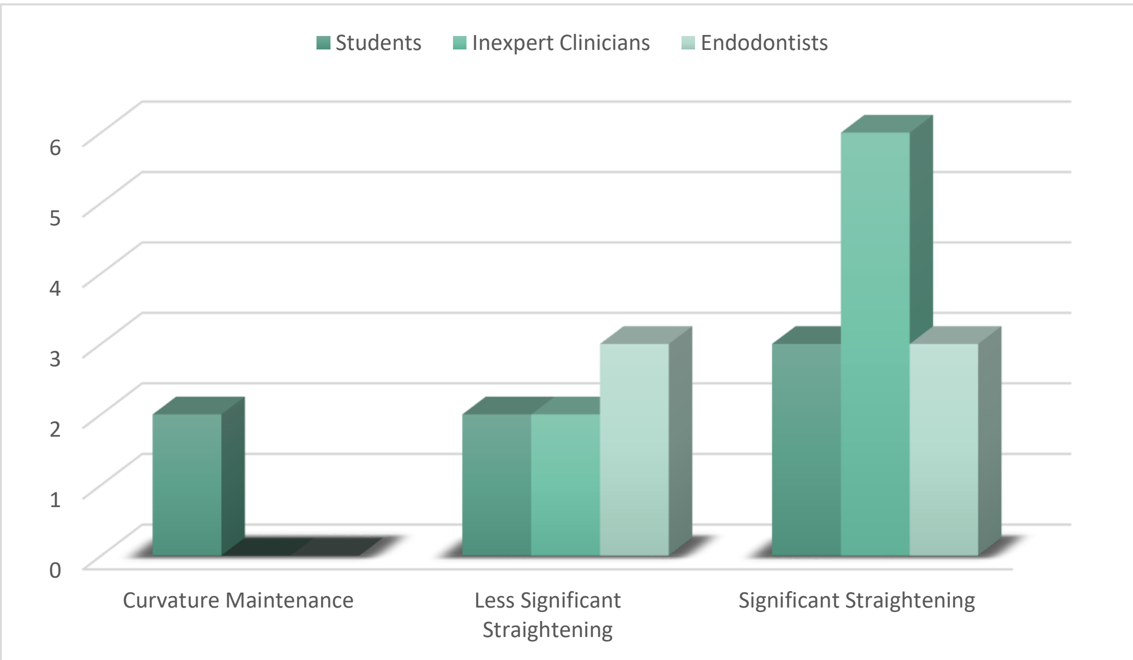
Table 7 - Descriptive statistics for transportation by instrumentation system, curvature and canal side. x̄: sample mean; *s:* sample standard deviation; IQR: interquartile range; CO: coronal; AP: apical

4.2. Qualitative analysis

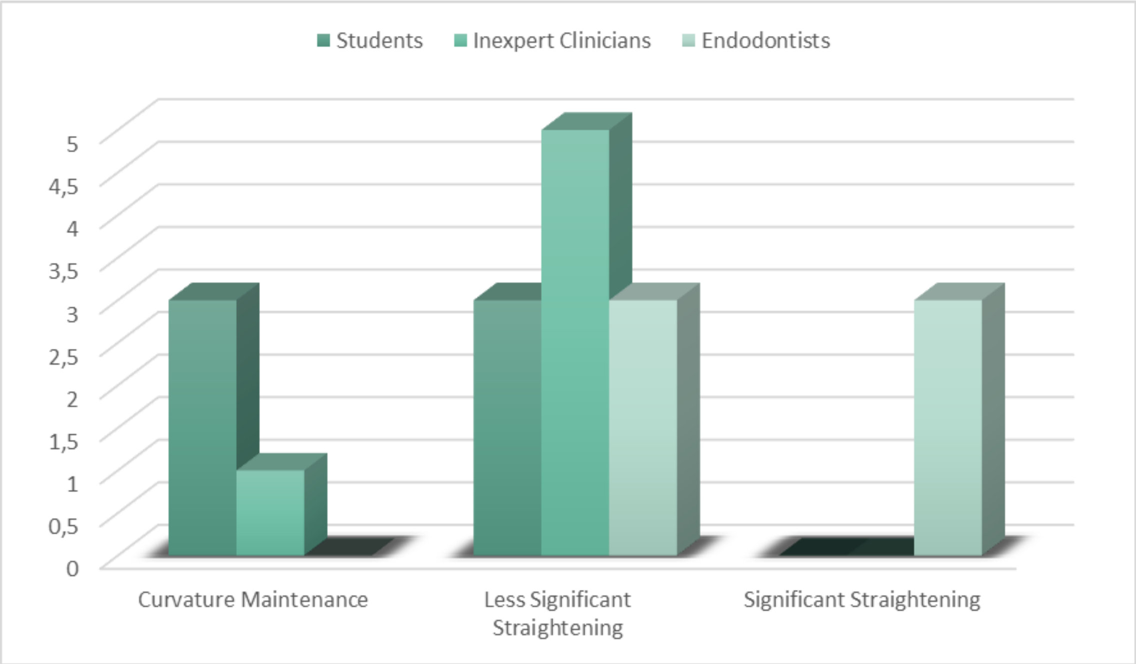
Considering each blinded examiner evaluation, the next graphics shows this evaluation taking into account the presence or absence of rectifications in the coronal and apical curvatures for each system file. Each examiner evaluated three superimposed images, randomly chosen, from each group.



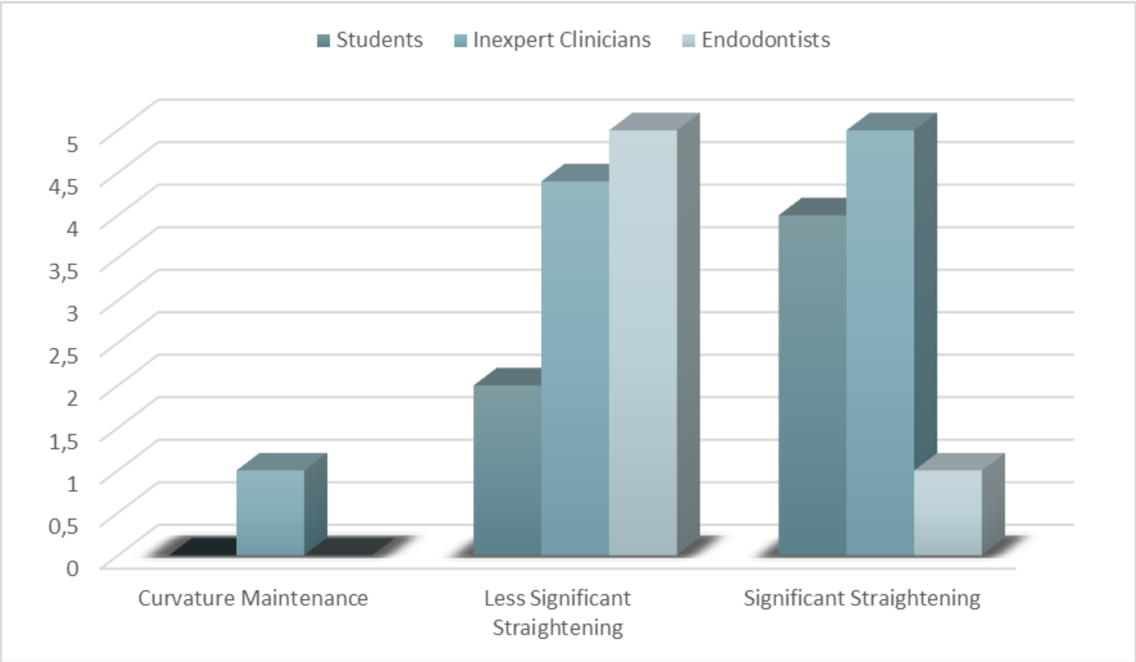
Graphic 1 - Evaluation of the coronal curvature prepared by ProTaper Gold™.



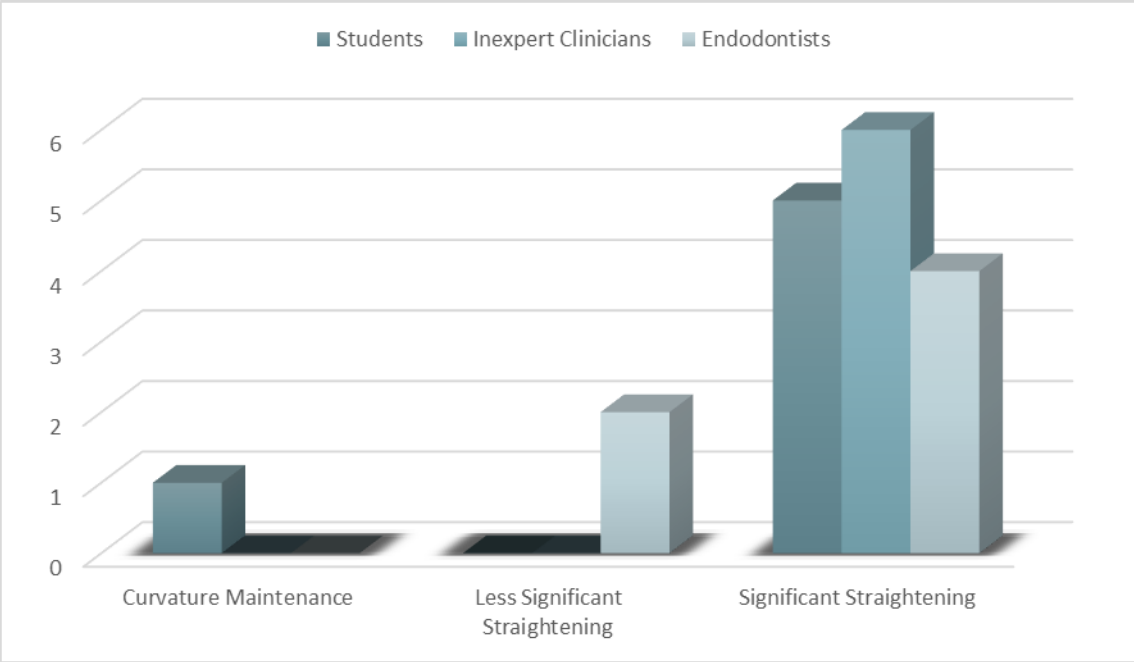
Graphic 2 - Evaluation of the coronal curvature prepared by TRUShape®.



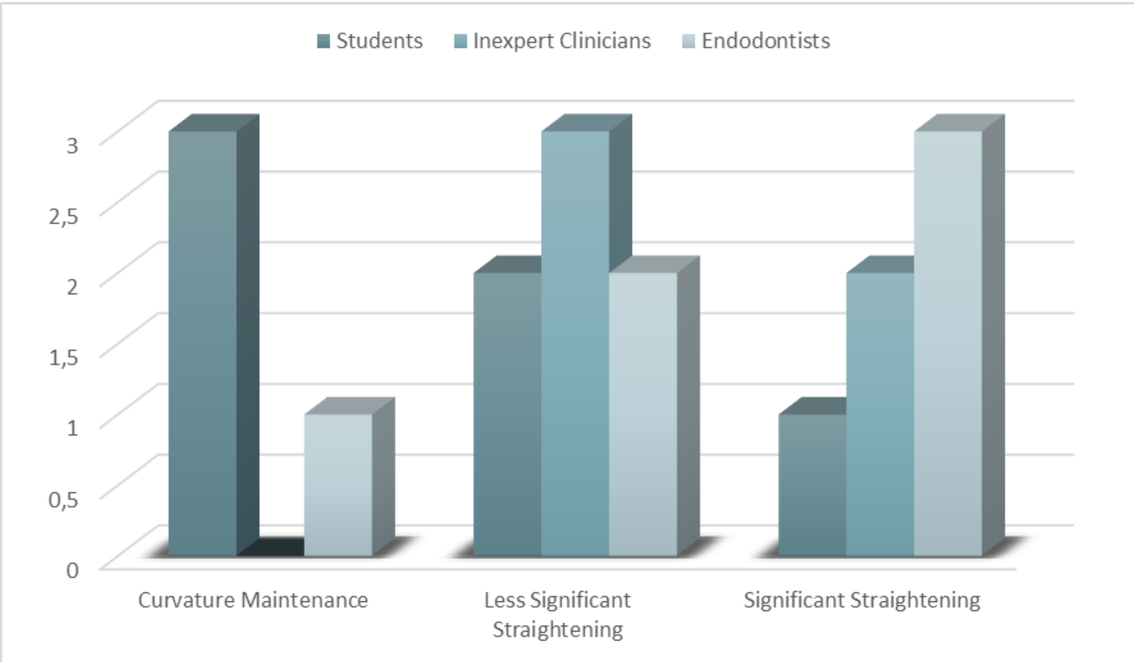
Graphic 3 - Evaluation of the coronal curvature prepared by HyFlex® EDM.



Graphic 4 - Evaluation of the apical curvature prepared by ProTaper Gold™.



Graphic 5 - Evaluation of the apical curvature prepared by TRUShape®.



Graphic 6 - Evaluation of the apical curvature prepared by HyFlex® EDM.

With the evaluation made by the examiners the following results were obtained:

Coronal curvature – The majority including students, inexpert clinicians and endodontists said that PG had significance straightening. Significance straightening in HF were just mentioned by endodontists and curvature maintenance was the opinion of the majority of the students in this rotary system. About TS group, the results were divided between less and significant straightening, the majority of inexpert clinicians mentioned more significant straightening.

Apical curvature – Students said that there were more significance straightening with PG while endodontist said with that there were more less straightening. With, TS most of the experts said that there was significance straightening. In HF, students supported curvature maintenance; inexpert clinicians less straightening and endodontist significance straightening.

5. DISCUSSION

Root canal shaping is one of the most significant procedures in endodontic treatment. The anatomy preservation is very important for three-dimensional obturation contributing to the success of treatment. (Peters OA, 2004)

The preparation of a curved canal, especially a double curved (S-shaped) canal is one of the most challenging procedures in root canal treatment. (Hiran et al, 2016)

Different, well-described preparation errors may result during the shaping of these curved root canals, such as ‘canal transportation,’ ‘straightening,’ or ‘deviation’. (Weine et al., 1975) As most root canals are curved (Schäfer et al. 2002), a high prevalence of preparation errors or canal aberrations has been reported. (Peters, 2004; Hulsmann et al. 2005)

The aim of this study was to compare the shaping ability of different NiTi systems: ProTaper Gold™; TRUShape®; HyFlex® EDM using simulated S-shaped root canals to standardize experimental conditions, but always regarding the fact that this method only gives 2D dimensions.

PTG, in several studies presented very good results when compared to another rotary system. HF and TS are two innovative rotary systems that have been recently introduced to the market.

Pre and post instrumentation studies indicate that the analysis of root canal outlines provides a standardized study design and extremely reproducible conditions. (Alrahabi and Alkady, 2017)

The rotary endodontic systems were of the same size but with different movements, tapers, designs, manufacturing processes file numbers, speeds and torques in the cutting area.

The use of simulated resin root canals allows standardization of degree, location and radius of root canal curvature in three dimensions as well as the ‘tissue’ hardness and the width of the root canals. Techniques using superimposition of pre and post instrumentation root canal outlines can easily be applied to these models thus facilitating measurement of deviation sat any point of the root canals. (Hulsmann et al.,2005)

Some studies mention that the problem of resin blocks is their distortion. (Rubio et al.,2017)

The disadvantages of using rotary instruments in resin blocks is the different hardness between resin and dentin and the heat generated, that which might distort the canal, reduce the cutting efficiency and lead to separation of the instrument. Furthermore, the cross-sections differ from natural teeth. (Zhang et al, 2008)

Some concern has been expressed regarding the differences in hardness between dentine and resin. Microhardness of dentine has been measured as 35–40 kg/mm2 near the pulp space, while the hardness of resin materials used for simulated root canals is estimated to range from 20 to 22 kg/mm2 depending on the material used. (Spyropoulos et al.,1987)

The first stage of the study comprised a quantitative analysis through observation of changes in root canal anatomy between pre and post instrumentation images followed by a qualitative observation made by examiners to compare the maintenance of the original root canal anatomy.

It is important to emphasize that no studies that compares PTG, TS and HF, could be found in the literature review, so it is not possible to directly compare the results of this study with others. Based on the results obtained with the quantitative analysis, the null hypothesis was rejected.

The results revealed that there were no significant differences on total canal transportation. There were no statistically significant differences between the three groups regarding coronal transportation or apical transportation.

On the outer side, only groups A and C presented significant differences. More canal transportation was observed in group A – PTG when compared with group C – HF. PTG also presented more canal transportation than HF on the outer side at apical curvature.

Not directly related but in literature there are studies that supports the results obtained. HF instruments demonstrated highest cyclic fatigue resistance, when compared with PTG. (Kaval et al, 2016). Another study results showed that HF instruments had higher resistance than TS. (Arias et al.)

A recent study that compared TS and PTG revealed that TS instruments had lower resistance to cyclic fatigue and lower flexibility compared with PTG (Elnaghy and Elsaka, 2017) which is not consistent with the results obtained in this study.

The second stage of the study comprised a qualitative analysis where endodontists, inexpert clinicians and students evaluated the maintenance of the original root canal anatomy, with the presence or absence, of the coronal and apical curvatures rectification. The differences registered are due to clinical experience and different levels of endodontic knowledge.

There was a significant difference in preparation time among NiTi systems, where the longest time was required for the ProTaper Gold, and the shortest for the HyFlex edm system. This is logical because the procedure with the ProTaper Gold required four instruments, whereas the HyFlex EDM system is a single-file system.

Atresic canals, high amplitude curvatures, higher than used in this study, a different temperature in the mouth, the operator holding the resin block by the hand during instrumentation are some critics to the present study.

Additional studies comparing endodontic files with different instrumentation movements, assessing other parameters and with a larger sample size are needed to understand which system file is the most indicated to shape severely curved root canals.

6. CONCLUSION

Lately, there have been not only important advances in technology applied to endodontology but also a significant development in NiTi alloys contributing to new improved instruments. Therefore, it is of utmost importance to evaluate and compare all the new instruments that appear on the market to realize which one fit the best our expectations.

Under the limitations of this study, HyFlex® EDM was the rotary file system which best maintained the original anatomy of the S-shaped canal with less modification of the original canal, revelling more flexibility compared to ProTaper Gold™ and TRUShape® systems. ProTaper Gold™ was the system that originated the greatest modification of the original canal, presenting a significant tendency to straighten apical curvature and outer side. During clinical practice, clinicians should be aware of the mechanical properties of the instruments chosen to best adapt a rotary system file to a specific case. It is important to respect the canal's original anatomy and avoid apical transportation, so the endodontic treatment will not be compromised.

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